

LABORATORY SIMULATION OF SPACE WEATHERING: ESR MEASUREMENTS OF NANOPHASE METALLIC IRON IN LASER-IRRADIATED OLIVINE AND PYROXENE SAMPLES. E. Kurahashi¹, C. Yamanaka², K. Nakamura³ and S. Sasaki¹, ¹Department of Earth and Planetary Science, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan, (e-mail: erika@space.eps.s.u-tokyo.ac.jp), ²Department of Earth and Space Science, Osaka University, Toyonaka, Osaka 560-0043, Japan, ³Astromaterials Research & Exploration Science (ARES), NASA Johnson Space Center, Houston, TX77058, USA.

Introduction: S-type asteroids are believed to be parent bodies of ordinary chondrites [1]. Although both S-type asteroids and ordinary chondrites contain the same mineral assemblage, mainly olivine and pyroxene, the reflectance spectra of the asteroids exhibit more overall depletion (darkening) and reddening, and more weakening of absorption bands relative to the meteorites. This spectral mismatch is explained by space weathering process, where high-velocity dust particle impacts should change the optical properties of the uppermost regolith surface of asteroids.

In order to simulate the space weathering, we irradiated nanosecond pulse laser beam onto pellet samples of olivine (8.97wt% FeO) and pyroxene (enstatite: 9.88wt% FeO, hypersthene: 16.70wt%). We got spectral changes in our samples similar to that by space weathering on asteroids [2, 3] and confirmed nanophase α -metallic iron particles, which were theoretically predicted [4, 5], not only on olivine but also on pyroxene samples by Transmission Electron Microscopy (TEM) [3,6]. Nanophase metallic iron particles were widely scattered throughout the amorphous rims developed along the olivine grains, whereas they were embedded in aggregates of amorphous in enstatite samples. Recently, We also measured laser-irradiated samples by ESR (Electron Spin Resonance). Strong ESR signals, characteristic to nanophase iron particles, are observed on irradiated olivine samples [7]. In this paper, we report the quantities of nanophase metallic iron particles in pyroxene samples by ESR observations in addition to olivine samples.

Experiments: To simulate space weathering, we use a solid-state Nd-YAG pulse laser beam (1064nm, 20Hz, 30mJ) with pulse duration of 6-8 nanoseconds, which is comparable with real dust impacts [2]. The focused beam was 500 μ m in diameter. We irradiated pellet samples (2cm in diameter) of olivine and pyroxene powders (<75 μ m) under a vacuum at $2-3 \times 10^{-5}$ torr. After laser irradiation, bi-directional reflectance spectra of samples were measured; spectrum range 250-2500nm was recorded at every 5nm [8]. ESR signals of the surface of laser-irradiated samples were measured using an ESR imaging device nondestructively [9]. Measurements were performed using a cylindrical TE₁₁₁ mode cavity with an aperture diameter of 3mm. The intensities were measured at room temperature

with a microwave power of $P = 3\text{mW}$, microwave frequency $f = 9.294\text{ GHz}$. Field modulation at 100 kHz was about 0.1 mT on the aperture area.

ESR observation: *Olivine samples:* Intense ESR signals derived from nanophase metallic iron particles are observed in all irradiated samples, though the non-irradiated sample shows no ESR signal (Fig. 1) [7]. All samples have the characteristic g-value (spectroscopic splitting factor) 2.10 ± 0.03 resonance, which are very close to the g-value in lunar materials arising from metallic iron (g-value = 2.12 ± 0.05) [10, 11]. The mean peak-to-peak linewidth is 70mT. ESR spectral shapes, g-value and strong intensities suggest the origin of this signal is nanophase metallic iron particles, which were confirmed by TEM. The ESR intensities of the olivine samples strengthen clearly with increasing irradiation times. These results suggest that the amount of nanophase metallic iron particles in olivine samples increases at higher space weathering degree. The ESR intensities are not in proportion to the irradiation times, because nanophase metallic iron should be evaporated and condensed on the samples over and again with repetitive laser irradiations.

Pyroxene samples: Fig. 2 and Fig. 3 show ESR results of hypersthene and enstatite samples, respectively. Both samples represent clear ESR signals derived from nanophase metallic iron particles like olivine samples. In hypersthene samples, g-value is 2.10 ± 0.1 and the mean peak-to-peak linewidth is 64 mT. Enstatite samples show g-value = 2.07. Enstatite samples including the non-irradiated one also show ESR signals derived from magnetite, which is contained in the samples as contaminations. In both samples, the ESR intensities clearly increase with irradiation times, but the intensities of the ten-times irradiated samples is almost close to those of the five-times irradiated one. This suggests the amount of nanophase iron particles does not change between five and ten-times irradiation.

Discussion: Fig. 4 shows the relation between relative amounts of nanophase metallic iron particles and reflectance change of each sample. In olivine samples, the amount of nanophase iron particles increase from five-times to ten-times irradiation, whereas the reflectance change is very small between five and ten-times irradiation. In pyroxene samples, hypersthene samples

that contain more FeO contents than enstatite generate more nanophase iron particles relative to enstatite samples at the same irradiation times. Between five-times and ten-times irradiations in both of hypersthene and enstatite, the difference of not only the amount of nanophase iron particles but also the reflectance change are very small.

Fig. 4 also shows that more nanophase metallic iron particles are produced on olivine samples than pyroxene samples. Moreover, when the content of the nanophase iron particles is equal, the spectra change of olivine samples is larger than those of pyroxene samples. This suggests that the reflectance spectra are affected not only by the amount of the nanophase metallic iron particles but also by the difference of their occurrence-form. The reflectance spectra of laser-irradiated olivine grains covered with the amorphous rim included the nanophase iron particles may change largely relative to those of pyroxene samples, which contain the amorphous aggregates embedded the nanophase iron particles, not the amorphous rim [6].

Conclusions: Amounts of nanophase metallic iron particles increase at higher space weathering degree in not only olivine samples but also pyroxene samples. Olivine is easier to occur nanophase metallic iron particles than pyroxene. Reflectance changes relative to the amount of nanophase metallic iron particles become moderate at higher space weathering degree in olivine samples. Amounts of nanophase iron particles change hardly at higher space weathering degree in pyroxene samples. Not only the amount of nanophase iron particles but also the difference of their occurrence-form may affect the changes of the reflectance spectra.

References: [1] Chapman C.R. (1996) *MPS*, 31, 699-725. [2] Yamada M. et al. (1999) *EPS*, 51, 1255-1265. [3] Sasaki S. et al. (2001) *Nature*, 410, 555-557. [4] Hapke B. et al. (1975) *Moon*, 13, 339-353. [5] Hapke B. (2001) *JGR*, 106, 10039 - 10073. [6] Nakamura K. et al. (2002) *MPS Suppl.*, 37, 7, A107. [7] Kurahashi et al. (2002) *EPS*, 54, e5-e7. [8] Kurahashi E. and Sasaki S. (2002) *LPS XXXIII*, #1479. [9] Ikeya M. et al. (1994) *Rev. Sci. Instrum.*, 65, 3670-3672. [10] Manatt S. L. et al. (1970) *Science*, 167, 709-711. [11] Tsay F.-D. and Chan S.I. (1971) *GCA*, 35, 865-875.

Figure 1-3: ESR spectra of olivine, hypersthene and enstatite, respectively. All irradiated samples show uniquely ESR signals derived from nanophase iron particles. **Figure 4:** Relation between reflectance change and relative amounts of nanophase iron particles of each sample. The vertical axis shows reflectance scaled to that of the non-irradiated sample at 550 nm. Each number beside a plot is irradiation time.

